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ORIGINAL PAPER

Woody species composition, diversity and structure of riparian forests of four watercourses types in Burkina Faso

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Abstract: Riparian forests are classified as endangered ecosystems in general, particularly in sahelian countries like Burkina Faso because of human-induced alterations and civil engineering works. The modification of this important habitat is continuing, with little attention being paid to the ecological or human consequences of these changes. The objective of this study is to describe the variation of woody species diversity and dynamic in riparian forests on different type of watercourse banks along phytogeographical gradient in Burkina Faso. All woody species were systematically measured in 90 sample plots with sides of 50 m × 20 m. Density, dominance, frequency and species and family importance values were computed to characterize the species composition. Different diversity indices were calculated to examine the heterogeneity of riparian forests. A total of 196 species representing 139 genera and 51 families were recorded in the overall riparian forests. The species richness of individuals with dbh ≥ 5cm increased significantly from the North to the South along the phytogeographical gradient and varied significantly between the different types of riparian forests. Similarity in tree species composition between riparian forests was low, which indicates high beta diversity and reflects differences in habitat conditions and topography. The structural characteristics varied significantly along the phytogeographical gradient and between the different types of riparian forests. The diameter class distribution of trees in all riparian forests showed a reverse "J" shaped curve except riparian forest of stream indicating vegetation dominated by juvenile individuals. Considering the ecological importance of riparian forest, there is a need to delineate and classify them along watercourses throughout the country.

Keywords: biodiversity; dynamic; species richness; rivers; streams; phytogeographical gradient.

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Introduction

Inside the intertropical belt, most dry ecosystems are subjected to demographic pressure, anthropic actions and climate hazards. Deforestation and surfaces of bare soil increase whereas biodiversity decrease (Menaut et al. 1995b; Maranz 2009). Tropical riparian forests survive as elongated forest fragments along rivers, where moisture supply is more continuous, fire frequency is lower, and soil fertility probably higher than elsewhere in the landscape (Veneklaas et al. 2005; Ceperley et al. 2010). Despite their size in patches, riparian forests are highly complex, divers and productive systems of great ecological, social, and economic values (Natta 2003; Ceperley et al. 2010; Naiman et al. 2010). They consist of valley floors and associated landforms created by fluvial sediment redistribution within the recent climate. Ecological investigations have demonstrated them to be a key landscape feature with substantial regulatory controls on environmental vitality (Maingi and Marsh 2002; Koponen et al. 2004; Veneklaas et al. 2005; Naiman et al 2008; Naiman et al. 2010).

Even though the riparian forests have been recognized for their high level of biodiversity, it is still unknown how many species are present for any system (Nilsson, 1992). More than 80% of riparian forest areas of North America and Europe have disappeared in the last 200 years. The general modification of this important habitat is continuing, with little attention being paid to the ecological or human consequences of these changes. In Burkina Faso, riparian forests are classified as endangered ecosystems because of human-induced alterations (deforestation and land-clearing) and civil engineering works (dam-building and hydroelectric developments). So, flow variability and fluctuations in channel width, which are necessary for maintaining the biodiversity of riparian systems, have been dramatically

decreased in many parts of the country through river impoundment, water management, and lowering of water tables.

The objective of this study is to describe the variation of woody species diversity and dynamic in riparian forests on different type of watercourse banks along phytogeographical gradient in Burkina Faso. Four water regime and channel width categories have been considered: permanent rivers, semi-permanent rivers, temporary rivers and streams (Table 1). We hypothesized that, the diversity and the dynamic of riparian forests woody plants are related to the both water regime and size of the channel width and the phytogeographical position. Because, substantial changes in riparian vegetation may occur without changing mean annual flow, as riparian vegetation is especially sensitive to changes in minimum and maximum flows, and in many cases, hydrologic alterations result in shifts in riparian plant community composition as well as senescence of woody communities (Naiman et al. 2010).

Materials and Methods

Study area

The study was carried out at four hydrographical basins in Burkina Faso, West Africa. The survey was conducted in the Nakambé basin (Nakambé, Nazinon and Singou), Mouhoun basin (Mouhoun and its tributaries), Comoé basin (Comoé and its tributaries) and Niger basin (Goudébo, Sirba and Bonsoaga) (Fig. 1). The riparian forests of the following localities were concerned: Saouga (14°22' N and 0°07' W), Ramsa (13°30' N and 2°07' W), Yalgo (13°33' N and 0°23' W), Dédougou (12°30' N and 3°33' W), Kougri (12°24' N and 1°05' W), Momba (12°08' N and 0°32' E), Folonzo (9°55' N and 4°36' W), Kou (11°11' N and 4°26' W), Singou (11°17' N and 1°01' E), Parc National Kaboré Tambi (11°27’ N and 1°09' W), Samogohiri (10°55’ N and 5°5’ W), Leyassa (11°38’ N and 4°7' W) and Cascades of Karfiguéla (10°43' N and 4°49' W). Phyto-geographically, the study sites are located in the four phytogeographical sectors defined by Fontès and Guinko (1995).

The North Sahelian sector’s annual rainfall varies between 400–500 mm. The number of rainy days per year varies between 30 and 40 days. The most frequently encountered soils at Gorom-Gorom are solonetz according to the FAO soil classification system (Driessen et al. 2001). The vegetation is characterized by Saharian and Sahelian species and the common species encountered along river’s banks are *Anogeissus leiocarpa, Combretum micranthum* and *Mitragyna inermis*.

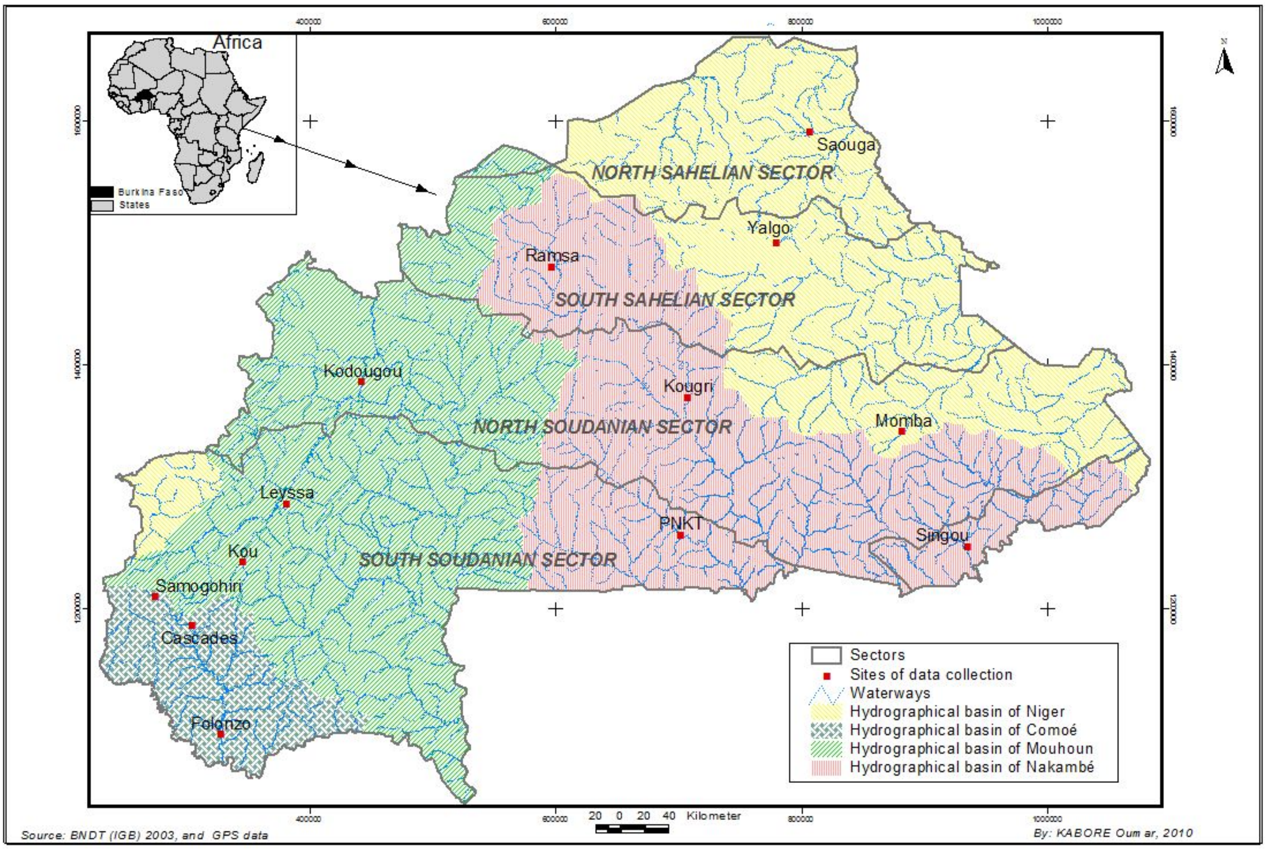

Fig. 1 Hydrographical basins map of Burkina Faso and location of the study sites

The South Sahelian sector’s annual rainfall varies between 500–700 mm. The number of rainy days per year varies between 40 and 50 days. The most frequently encountered soils at Ramsa and Yalgo are lithosols. The vegetation is characterized by Saharian, Sahelian and some Sudanian species and the common species encountered along river’s banks are *Anogeissus leio-*

carpa, Mitragyna inermis, *Acacia ataxancatha* and *Acacia seyal*.

The North sudanian sector's annual rainfall varies between 700–900 mm. The number of rainy days per year varies between 40 and 70 days. The most frequently encountered soils at Dedougou, Kougri and Momba are lithosols. The vegetation is characterized by sudanian and some sahelian species. The common species encountered along permanent rivers stand (Mouhoun) are *Mitragyna inermis, Vitex chrysocarpa, Acacia seyal, Ptercarpus santalinoides, Acacia poyacantha* (Savadogo et al. 2007) and the common species along temporary rivers are *Mitragyna inermis* and *Crateva adansonii* (Fontès & Guinko 1995).

The South sudanian sector's annual rainfall varies between 900–1100 mm. The number of rainy days per year varies between 70 and 90 days. The most frequently encountered soils at Folonzo, Kou, Singou, PNKT, Samogohiri, Leyassa and Cascades of Karfiguéla are ferralsols. The vegetation is characterized by sudanian species associated with Guinean riparian species such as *Cola laurifolia, Manilkara multinervis, Elaeis guineensis, Dialium guineense*, *Antiaris africana, Antidesma venosum*, *Carapa procera*, *Chlorophora excelsa*, *etc* (Fontès and Guinko 1995).

Data collection

The plant survey was carried out at the beginning and the end of three rainy seasons (May-June and September-October 2007, 2008 and 2009) when species can be easily identified. The survey was conducted in 13 sites through four types of riparian forests, different in their channel width and their water regime (Table 1): permanent rivers (Mouhoun and Comoé), semi-permanent rivers (Singou and Nazinon), temporary rivers (Nakambé, Goudebo, Bonsoaga and Sirba) and streams (Kou, Leyassa; Samogohiri, Cascades de karfiguéla). A total of 90 plots (14 along permanent rivers, 10 along semi permanent rivers, 33 along temporary rivers, 33 along streams) were established for data collection (Table 6). The plots were rectangular with sides of 50 m × 20 m. The plots were established in homogeneous stands through riparian forests. Plots were spaced about 100 to 200 m from a random starting point. Each sample plot was systematically surveyed and the woody species were recorded and specimens taken for the herbarium. The nomenclature of species followed the International Plant names Index (www.ipni.org). The following variables were also recorded on the individuals with dbh ≥ 5cm: the number of individual per species, the height and the diameter at 1.30 m of each individual.

Data analysis

The species composition of the plots was described by the following parameters:

$$\text{Basal area} = D^2_{1.30}\,\frac{\pi}{4}$$

$$\text{Relative Dominance} = \frac{\text{Total basal area of a species}}{\text{Total basal area of all species}} \times 100$$

$$\text{Relative Density} = \frac{\text{Number of individuals of a species}}{\text{Total number of individuals}} \times 100$$

$$\text{Relative Diversity} = \frac{\text{Number of a species in a family}}{\text{Total number of species}} \times 100$$

$$\text{Frequency} = \frac{\text{Number of plots in which the species occurs}}{\text{Total number of plots}} \times 100$$

$$\text{Relative Frequency} = \frac{\text{Frequency of a species}}{\text{Sum of all frequencies}} \times 100$$

The importance value index (IVI) = relative dominance + relative density + relative frequency

The family importance value (FIV) = relative dominance + relative density + relative diversity.

where $D_{1.30}$ is the diameter of the trunk to 1.30 m above ground. The theoretical range for relative dominance, relative frequency, relative density and relative diversity is 0–100%, so the IVI of species and FIV may vary between 0 to 300%.

Table 1. Water height and flow maximum variations between month values from thirty last years

Type of water-courses	Sites/watercourses	Height (cm)	Dis-charge (m^3/s)	River shape
Permanent River	Folonzo/ Comoé	501.45	101.212	Speed sided
	Dédougou/Mouhoun	401.51	59.8	Speed sided
Semi-permanent River	PNKT/Nazinon	309.83	31.7	Speed sided
	Singou/Singou	-	-	Speed sided
Temporary River	Fada/Bonsoaga	282.79	15.2	No Speed sided
	Ramsa/Nakambé	138.33	14.571	No Speed sided
	Gorom-gorom/Goudebo	-	-	No Speed sided
Stream	Samogohiri/Comoé tributary	14.34	0.112	Speed sided
	Kou-Nasso/Mouhoun tributary	21.65	0.67	No Speed sided
	Karfiguela/Comoé tributary	54.47	0.56	No Speed sided
	Leyassa/Mouhoun tributary	-	-	No Speed sided

Source : Direction générale des ressources en eau (DGRE). The mean values of the data were calculated for the period of 1979 to 2009.

Diversity indices were computed for a better understanding of plant community structure and composition. They provide more information about community composition than simply species richness; they also take the relative abundances of different species into account. Species richness is often insufficient to compare two communities because it doesn't take into account the relative dominance of each species (Krebs 1999). By taking relative abundance into account, a diversity index depends not only on species richness but also on the evenness, or equitability, with which individuals are distributed among the different species. Therefore, we calculated Shannon's diversity Index (H), Shannon's Evenness (E_H) and Simpson's Reciprocal Index (1/D).

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

$$E_H = H/\ln S$$

$$1/D = \frac{1}{\sum_{i=1}^{S} p_i^2}$$

where S = total number of species in the community (richness) and p_i = is the relative abundance of the ith species in a plot. These indices are widely employed to measure biological diversity (Magurran 2004). Shannon's diversity Index (H) and Simpson's Reciprocal Index (1/D) take into account for both species richness and evenness. Shannon's diversity Index tends to increase with the number of species in the sample. The value of Simpson's Reciprocal Index (1/D) starts with 1 as the lowest possible figure (community containing only one species). The higher value indicates the greater diversity. The maximum value is the number of species in the sample. Shannon's evenness measures the relative abundance of the different species making up the richness of an area. It assumes a value between 0 and 1 with 1 being complete evenness.

To evaluate β-diversity (similarity between riparian forests), Jaccard's similarity index and Sorensen's similarity index were computed. Jaccard's coefficient of similarity and Sorensen's coefficient of similarity was calculated based on presence/absence data of the species. They were calculated from the following equations:

$$\text{Jaccard index } (C_{\text{j}}) = \frac{j}{a+b-j}$$

$$\text{Sorensen index (Cs)} = \frac{2j}{2\text{j}+a+b}$$

where j = number of species held in common, a = number of species found at only the site A and b = number of species found at only the site B.

These indices potentially vary between 0 and 1, and a value close to 1 indicates greater similarity between patches, and hence low β-diversity (Magurran 2004). Jaccard's Index and Sorensen's Quotient of Similarity are both rather sensitive to differences in sample size.

Structural characteristics (stem density, basal area, mean diameter and diameter and height class distributions) were computed for each plot and averaged per vegetation unit for all individuals with a dbh ≥ 5 cm. The plants were grouped into ten diameter classes of 5 cm interval: Class 1 = [5-10], Class 2 =]10-15], Class 3 =]15-20], Class 4 =]20-25], Class 5 =]25-30], Class 6 =]30-35], Class 7=]35-40], Class 8 =]40-45], Class 9 =]45-50], Class 10 = dbh > 50 cm and into seven height classes at 5 m intervals: Class 1 =]0-5], Class 2 =]5-10], Class 3 =]10-15], Class 4 =]15-20], Class 5 =]20-25], Class 6 =]25-30], Class 7 = height > 30 m.

Species richness and abundance were analysed with the generalized linear models using penalized quasi-likelihood with Poisson errors. The phytogeographical gradient and the category of channel width and water regime were treated as categorical fixed factors. Generalized linear models with Poisson errors were used in order to account for the non-normal errors distribution and the increasing variances with means that are associated with count data. Penalized quasi-likelihood estimation was used in order to account for over dispersion (Crawley 2005). The basal area, the mean diameter, Shannon's diversity Index, Shannon's Evenness and Reciprocal Index were analysed using linear models, with the same categorical factors. These data fulfilled the assumptions of normality and variance homogeneity. All the statistical analyses and diversity calculation were performed within the R statistical package (R development Core Team 2007). The vegan package, developed by the Finnish ecologist Jari Oksanen, was used to calculate diversity indices. The car package was used to perform the ANOVA using the type III sum of squares for none orthogonal design. The graphs were performed with the Microsoft Office Excel 2007 software.

Results

Taxonomic diversity

A total of 196 species representing 139 genera and 51 families were recorded in the overall riparian forests of which in one hand 19, 23, 77 and 162 species were encountered in North Sahelian, South Sahelian, North Sudanian and South Sudanian sectors respectively; in the other hand 68, 29, 71 and 139 species were encountered along permanent rivers, semi-permanent rivers, temporary rivers and streams respectively (Appendix).

The species richness of individuals with dbh ≥ 5 cm increased significantly from the North to the South along the phytogeographical gradient ($F_{[3;\,86]}$ = 3.17; P = 0,029; Table 2) and varied significantly between the different types of riparian forests ($F_{[3;\,86]}$ = 2.73; P = 0.049; Table 2). The highest species richness was found in the South Sudanian sector (80 species) and along streams (68 species); the lowest species richness was in the North Sahelian sector (11 species) and along semi-permanent rivers (13 species).

The importance value of species varied along the phytogeographical gradient and among the different types of riparian forests (Table 3). The most important species in the riparian forests were in one hand *Diospyros mespiliformis*, *Piliostigma reticulatum, Anogeissus leiocarpa, Balanites aegyptiaca* and *Acacia raddiana* in North Sahelian sector, *Acacia seyal, Piliostigma reticulatum, Balanites aegyptiaca, Mitragyna inermis* and *Acacia sieberiana* in South Sahelian sector, *Pterocarpus santalinoides, Mitragyna inermis, Diospyros mespiliformis, Daniellia olivieri, Anogeissus leiocarpa* in North Sudanian sector, *Berlinia grandiflora, Vitex chrysocarpa, Syzygium guineense, Cola laurifolia and Capara procera* in South Sudanian sector; in the other hand *Pterocarpus santalinoides, Syzygium guineense, Cola laurifolia, Diallium guinense* and *Diospyros mespiliformis* along permanent rivers, *Vitex chrysocarpa, Mitragyna inermis, Cola laurifolia, Syzygium guineense* and *Morelia senegalensis* along

semi-permanent rivers, *Diospyros mespiliformis, Piliostigma reticulatum, Mitragyna inermis, Acacia seyal* and *Anogeissus leiocarpa* along temporary rivers and *Berlinia grandiflora, Carapa procera, Elaeis guineensis, Cola cordifolia* and *Ceiba pentandra* along streams.

Table 2. Summary of riparian forests' diversity along phytogeographical gradient (A) and different watercourses (B) in Burkina Faso

(A) Phytogeographical gradient	Families	Genera	Species richness (S)	Shannon's diversity Index	Shannon's Evenness	Simpson's Reciprocal Index.
North Sahelian	8	10	11	0.73 ± 0.19	0.57 ± 0.10	2.34 ± 0.57
South Sahelian	10	12	14	1.01 ± 0.10	0.75 ± 0.05	2.50 ± 0.51
North Sudanian	20	32	44	1.40 ± 0.12	0.77 ± 0.03	4.00 ± 0.45
South Sudanian	34	64	80	1.48 ± 0.07	0.79 ± 0.02	4.39 ± 0.32

(B) watercourses	Families	Genera	Species richness (S)	Shannon's diversity Index	Shannon's Evenness	Simpson's Reciprocal Index.
Permanent rivers	20	30	32	1.59 ± 0.12	0.77 ± 0.04	4.50 ± 0.45
Semi-permanent rivers	12	13	13	1.06 ± 0.13	0.71 ± 0.06	2.76 ± 0.39
Temporary rivers	15	23	33	1.06 ± 0.10	0.71 ± 0.04	2.99 ± 0.34
Streams	29	57	68	1.55 ± 0.08	0.81 ± 0.02	4.75± 0.42

Table 3. The five most abundant species in each vegetation patch according to decreasing order

Watercourse type	IVI	Phytogeographical sectors	IVI
Permanent Rivers		North sahelian	
Pterocarpus santalinoides	46.90	*Diospyros mespiliformis*	75.80
Syzygium guineense	41.16	*Piliostigma reticulatum.*	58.65
Cola laurifolia	30.73	*Anogeissus leiocarpa*	31.90
Dialium guineense	28.44	*Balanites aegyptiaca*	30.32
Diospyros mespiliformis	18.27	*Acacia raddiana*	26.29
Total	165.51	Total	222.96
Remains	134.49	Remains	77.04
Semi-permanent Rivers		South sahelian	
Vitex chrysocarpa.	101.34	*Acacia seyal*	42.32
Mitragyna inermis.	61.05	*Piliostigma reticulatum*	31.22
Cola laurifolia.	51.62	*Balanites aegyptiaca*	26.89
Syzygium guineense	21.64	*Mitragyna inermis*	23.25
Morelia senegalensis	19.23	*Acacia sieberiana*	20.46
Total	254.88	Total	144.14
Remains	45.12	Remains	155.86
Temporary Rivers		North sudanian	
Diospyros mespiliformis	45.31	*Pterocarpus santalinoides.*	106.78
Piliostigma reticulatum	34.63	*Mitragyna inermis*	49.77
Mitragyna inermis.	33.82	*Diospyros mespiliformis.*	39.48
Acacia seyal	27.93	*Daniellia oliveri*	29.72
Anogeissus leiocarpa	26.38	*Anogeissus leiocarpa*	24.66
Total	168.07	Total	250.41
Remains	131.93	Remains	49.59
Streams		South sudanian	
Berlinia grandiflora	50.34	*Berlinia grandiflora*	33.27
Carapa procera	31.06	*Vitex chrysocarpa.*	22.62
Elaeis guineensis	19.85	*Syzygium guineense*	21.57
Cola cordifolia	19.39	*Cola laurifolia*	18.86
Ceiba pentandra	19.32	*Carapa procera.*	18.46
Total	139.96	Total	114.78
Remains	160.04	Remains	185.22

IVI : Importance Value Index

The family importance value varied along the phytogeographical gradient and among the different types of riparian forests (Table 4). The most important families were in one hand Ebenaceae, Combretaceae, Caesalpiniaceae, Mimosaceae, Rubiaceae and Balanitaceae in North Sahelian sector, Mimosaceae, Caesalpiniaceae, Balanitaceae, Rubiaceae and Ebenaceae in South Sahelian sector, Caesalpiniaceae, Combretaceae, Fabaceae, Rubiaceae, Ebenaceae and Mimosaceae in North Sudanian sector, Caesalpiniaceae, Sterculiaceae, Lamiaceae, Rubiaceae and Meliaceae in South Sudanian sectors; in the other hand Fabaceae, Caesalpiniaceae, Myrtaceae, Rubiaceae, Sterculiaceae and Euphorbiaceae along permanent rivers, Lamiaceae, Rubiaceae, Sterculiaceae and Myrtaceae along semi-permanent rivers, Caesalpiniaceae, Combretaceae, Mimosaceae, Ebenaceae and Rubiaceae along temporary rivers, Caesalpiniaceae, Meliaceae, Moraceae, Bombacaceae, Sterculiaceae along streams.

Species diversity and similarity

The diversity indices (Shannon's Index and Simpson's Reciprocal Index) varied significantly along the phytogeographical gradient ($F_{[3;\ 86]} = 9.18$, $P < 0.001$; $F_{[3;\ 86]} = 4.75$, $P = 0.004$ respectively; Table II.A) and among the different type of riparian forests ($F_{[3;\ 86]} = 3.81$, $P = 0.013$; $F_{[3;\ 86]} = 2.81.15$, $P = 0.044$ respectively; Table 2.B). The most diverse riparian forests were in the South and North Sudanian sectors; along permanent rivers and streams (Table 2). Shannon's Evenness varied significantly along the phytogeographical gradient ($F_{[3;\ 86]} = 5.31$, $P = 0.002$; Table 2.A). The distribution of the species in the riparian forests of the North Sahelian sector was less even (0.57±0.10) than in the others phytogeographical sectors, but Shannon's Evenness was high and significantly similar within the different types of riparian forests ($F_{[3;\ 86]} = 1.28$, $P = 0.28$; Table II.B) with a global mean value of 0.78 ± 0.02.

Table 4. Summary of the families importance value (FIV) indices along phytogeographical gradient and different types of watercourse

Families	Watercourse type				Phytogeographical sector			
	PR	SPR	TR	STR	N-Sah.	S-sah.	N-sud.	S-sud.
Anacardiaceae			7.79	5.50			6.56	4.05
Annonaceae	3.25	9.57		3.87				3.52
Apocynaceae	3.64		3.76	10.98		8.86	2.86	7.52
Arecaceae				16.37				9.90
Balanitaceae			18.03	1.83	24.10	32.79	7.28	1.49
Bignoniaceae				1.96				1.53
Bombacaceae				19.12				13.83
Boraginaceae				4.41				2.69
Caesalpiniaceae	37.88		67.05	58.13	38.27	49.12	50.49	47.02
Capparaceae			3.30		9.74			
Celastraceae	3.47	8.10		1.70			2.68	2.72
Chrysobalanaceae		13.36						2.22
Clusiaceae	3.60	10.12		1.78			2.82	3.18
Combretaceae	11.50		52.15	6.53	51.27	15.50	47.38	4.58
Dilleniaceae				2.04				1.52
Dioncophyllaceae	3.27			1.56				1.36
Ebenaceae	14.98	11.56	39.69	3.60	101.17	20.02	21.81	3.64
Euphorbiaceae	19.27	8.07		11.76			12.06	11.62
Fabaceae	41.77		9.12	6.68	11.56	13.87	42.22	5.97
Flacourtiaceae				1.57				1.31
Lamiaceae	7.26	90.28	3.97	5.50			10.29	25.06
Meliaceae	11.20		5.42	34.43			12.38	20.79
Mimosaceae	16.80	8.83	45.08	12.56	34.47	103.85	21.28	12.58
Moraceae				22.06				16.40
Myrtaceae	36.94	21.00		5.78			3.17	17.83
Opiliaceae				1.56				1.30
Rhamnaceae	4.21		3.43			7.95	3.52	
Rhizophoraceae	14.62							5.61
Rubiaceae	27.84	66.50	31.90	14.60	29.42	32.37	38.49	24.67
Sapindaceae	3.36	7.90		7.01			2.54	5.89
Sapotaceae	10.46		6.04	11.76		15.67	3.73	11.73
Sterculiaceae	24.69	44.73		18.51			5.95	25.34
Tiliaceae			3.28				2.47	
Ulmaceae				6.87				4.38

PR: Permanent Rivers; SPS: Semi-permanent Rivers; TR: Temporary Rivers; Streams; Nsah.:North Sahelian; Ssah.: South Sahelian; Nsud.: North Sudanian; Ssud. South Sudanian

According to similarities indices, the similarity varied between phytogeographical sectors (Table 5. A). The most similar sectors were the North and South Sahelian sectors (Jaccard Index = 0.67 and Sorensen Index= 0.80); the least similar sectors were North Sahelian and South Sudanian sectors (Jaccard Index = 0.03 and Sorensen Index = 0.07) and the South Sahelian and South Sudanian sectors (Jaccard Index = 0.04 and Sorensen Index = 0.08). The similarity between the difference types of riparian forests was fairly low and varied among them (Table 5.B). The highest similarity value was observed between permanent and Semi-permanent rivers (Jaccard Index = 0.29 and Sorensen Index = 0.44).

Table 5. Summary of similarity indices between riparian forests along phytogeographical gradient and different types of watercourse

A	Index	North Sahelian	South Sahelian	North Sudanian
	Jaccard			
	South Sahelian	0.67		
	North Sudanian	0.15	0.23	
	South Sudanian	0.03	0.04	0.22
	Sørensen			
	South Sahelian	0.80		
	North Sudanian	0.25	0.38	
	South Sudanian	0.07	0.08	0.35
B	**Index**	**Permanent**	**Semi-permanent**	**Temporary**
	Jaccard			
	Semi permanent	0.29		
	Temporary	0.14	0.07	
	Stream	0.18	0.07	0.11
	Sørensen			
	Semipermanent	0.44		
	Temporary	0.25	0.13	
	Stream	0.30	0.12	0.20

Stand structure

The plant density increased significantly from the North to the South along the phytogeographical gradient ($F_{[3; 86]} = 5.57$; $p = 0.002$; Table 6.A) and varied significantly between the different types of riparian forests ($F_{[3; 86]} = 27.88$; $p < 0.001$; Table 6.B). The highest densities were found in South Sudanian sector (438.16±41.04 indvaduals·ha^{-1}) and along permanent rivers (727.14±79.13 indvaduals·ha^{-1}); the lowest densities were in North Sahelian sector (233.00±55.87 indvaduals·ha^{-1}) and along streams (283.33±19.96 indvaduals·ha^{-1}). The mean value of the dbh varied significantly along the phytogeographical gradient ($F_{[3; 86]} = 5.65$; $p = 0.001$; Table 6.A) and among the different types of riparian forests ($F_{[3; 86]} = 8.57$; $p< 0.001$; Table 6.B). The highest values were found in South Sudanian sector (26.22±1.61 cm) and along streams (31.34±1.88 cm).

Table 6. Summary of species structural characteristics for each type of riparian forest (mean±S.E)

Sectors	Samples plots	Density (Ind./ha)	DBH (cm)	Basal area (m²/ha)
A				
North Sahelian	10	233.00±55.86	23.51±2.54	15.98±4.76
South Sahelian	11	402.73±73.42	15.72±1.86	8.25±1.28
North Sudanian	20	416.00±43.02	20.20±2.43	17.62±3.17
South Sudanian	49	438.16±41.04	26.22±1.61	28.69±2.61
Riparian forests	**Samples plots**	**Density (Ind./ha)**	**DBH (cm)**	**Basal area (m²/ha)**
B				
Permanent rivers	14	727.14±79.13	16.37±0.85	21.78±2.86
Semipermanents rivers	10	637.00±71.56	18.48±1.95	21.10±2.70
Temporary rivers	33	322.73±33.23	20.70±1.78	14.22±2.41
Streams	33	283.33±19.96	31.34±1.88	31.02±3.65

The basal area varied significantly from the North to the South along the phytogeographical gradient ($F_{[3; 86]} = 6.52$; $p < 0.001$;

Table 6.A) and was significantly similar among the different types of riparian forests ($F_{[3; 86]} = 1$; $p = 0.40$; Table 6.B). The highest basal area was found in South Sudanian sector (28.69±2.61 $m^2 \cdot ha^{-1}$) and the lowest was in the South Sahelian sector (8.25±1.28 $m^2 \cdot ha^{-1}$). The overall mean value of the basal area among the different types of riparian forests was 22.32±1.84 $m^2 \cdot ha^{-1}$.

The diameter class distribution of trees of the different types of riparian forests showed a reverse "J" shaped curve (Fig. 2), but the pattern along streams included a slight deviation in the first class (5−10). The majority of individuals (61.19%) along permanent rivers, 49.29% along semi-permanent rivers, 46.58%, along temporary watercourses) were in the lowest dbh classes (5−10 and 10−15). Concerning individuals with dbh ≥ 50 cm, 1.58%, 3.11%, 6.34% and 15.59% were found respectively along permanent rivers, semi-permanent rivers, temporary rivers and streams. The height classes distribution of trees was a skewed bell shaped curve for all the riparian forests types (Fig. 3). The high number of individuals had a height comprise between 10 to 15 m for all the riparian forests types. The percentage of individuals with height ≥ 20 m is high in the riparian forest along streams (25.95%) and low in others (5%).

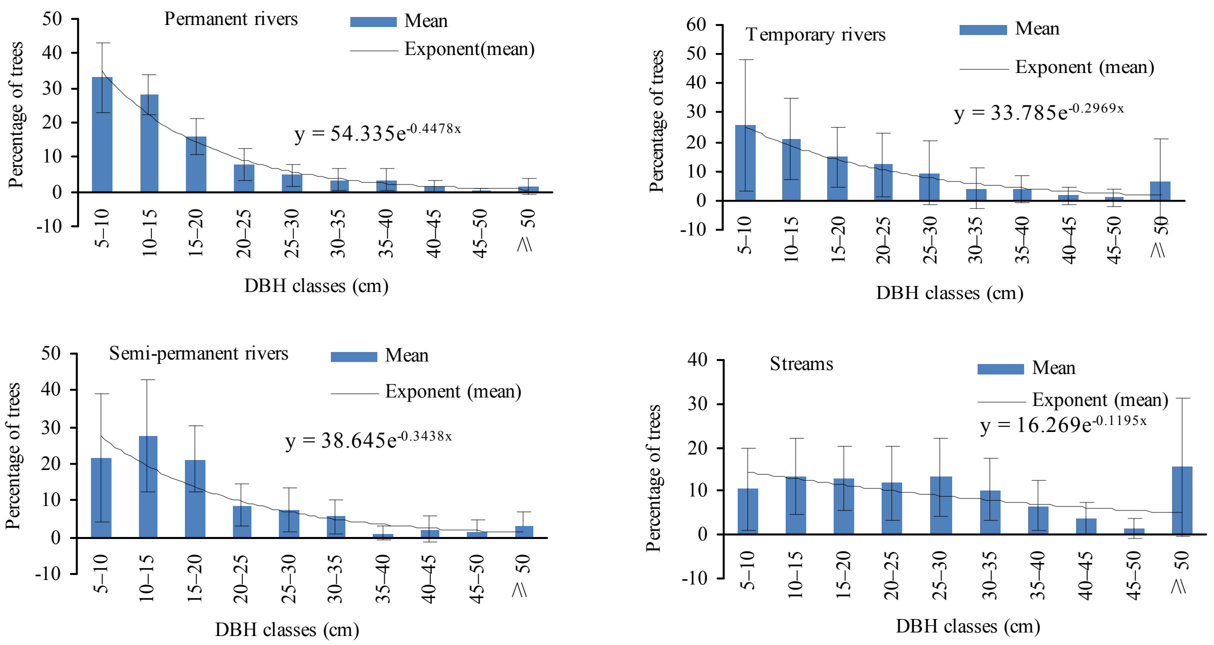

Fig. 2 Diameter class distribution of individuals ≥ 5 cm dbh in riparian forests along four watercourse types in Burkina Faso.

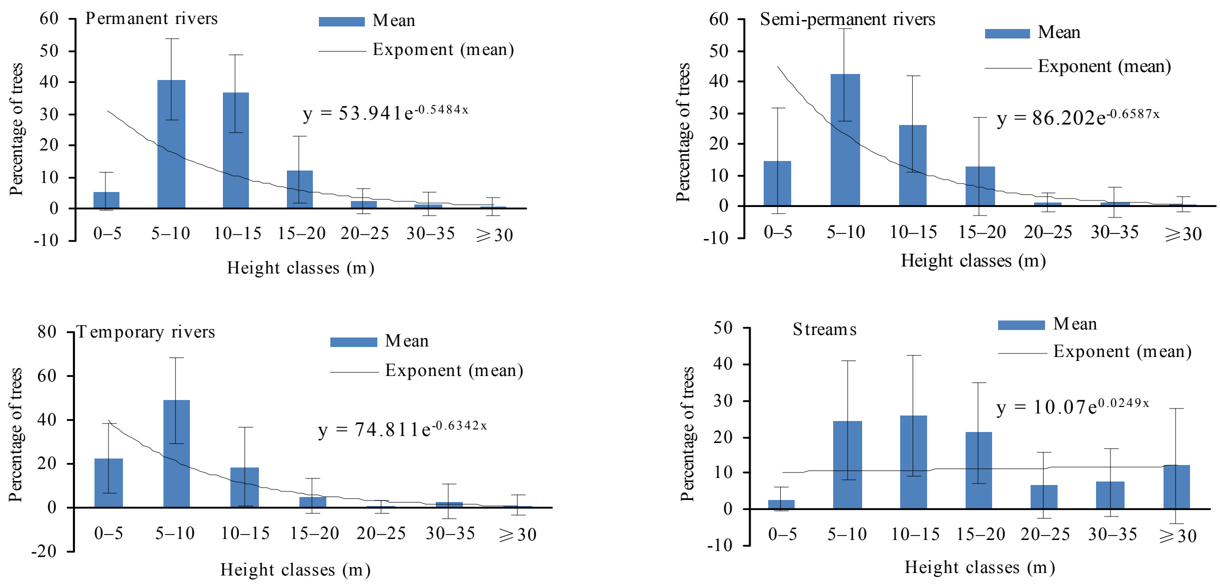

Fig. 3 Height class distribution of individuals ≥ 5 cm dbh in riparian forests along four watercourses types in Burkina Faso.

Discussion

The overall species richness reported in this study accounts for 70% of the entire native woody species of Burkina Faso. Lebrun (1991) reported that the woody flora (trees, small shrubs and climbers) at the country level includes 55 families, 214 genera and 376 species (with 96 exotic species). This finding is in agreement with earlier studies that demonstrate unusually high levels of biodiversity in riparian forests (Pither and Kellman 2002; Suzuki et al. 2002; Natta, 2003; Tockner et al. 2008). The reasons for the high diversity of woody plants may be related to the intensity and frequency of floods, small-scale variation in topography and soil as a result of lateral migration of rivers' channels, variations in climate as streams flow from high to low altitudes or across biome, and disturbances regimes imposed on the riparian forest by upland environment (Naiman et al. 1993; Suzuki et al. 2002, Naiman et al. 2008). These forces create a mosaic of habitats in a non-equilibrium system, which allows a wide variety of species to co-exist. It is well known that environmental heterogeneity, productivity and resource diversity have major effect on species richness (Solbrig 1991; Menaut et al. 1995a; Koponen et al. 2004).

The species diversity varied between the phytogeographical sectors. The species richness increased with the phytogeographical gradient from the north to the south. This is in agreement with the model of latitudinal diversity gradients that indicates a gradual increase of species richness from the poles to the equator (Gaston 2000; Clarke and Gaston 2006; Gaston 2007). More than 30 hypotheses have been advanced to explain the phenomenon, but the support for the role of contemporary climate dominates the current literature (Gough and Field 2007). However, an integration of contemporary ecological and historical explanations is increasingly advocated. So, the increase of the species richness in riparian forests along the phytogeographical gradient could be related to (1) time: diversity increases with time because it is a product of evolution, a process which proceeds more rapidly in tropical and stable environments; (2) spatial heterogeneity: as the physical environment become more diverse, so does the biota; (3) competition: inter-specific competition is increased in the tropics, reducing niche size and hence increasing the number of niches; (4) predation: the greater number of predators and parasites in the tropics reduces the size of prey population, which, in turn, reduces inter-specific competition and allows the addition of new species; (5) climatic stability and favourable environments: environments that are stable have more constant supply of resource and provide favourable conditions for many species; (6) productivity: productivity is greater in the tropics, and the more energy available to the system the greater will be the diversity; (7) disturbance: moderate disturbance retards competitive exclusion and enhances diversity (Osborne 2000; Suzuki et al. 2002; Tilman et al. 2006). These factors operate together to determine the species diversity along the phytogeographical gradient. They explain the variation of the relative importance of each species and each family (IVI, FIV), the species diversity indices (Shannon's Index and Simpson's Reciprocal Index) and the β-diversity (Jaccard Index and Sorensen Index). In fact, the riparian forests of the Sudanian domain (South and North Sudanian sectors) are the most diverse. The low evenness of the species distribution met in the North Sahelian sector can be attributed to the harshness of the climate and anthropogenic disturbances. The similarity between the phytogeographical sectors decreases gradually and this means a high β-diversity (rate of change of species along a gradient from one habitat to another) between the North Sahelian sector and the South Sudanian sector. It accentuated the importance of latitudinal gradient in explaining species diversity at larger spatial scales in riparian ecosystems.

There was also species richness, taxonomic diversity, species diversity variations among the different types of riparian forests. This variation is related to variable flood regimes, geomorphic channel processes, altitudinal climate shifts, and upland influence on the fluvial corridor (Naiman et al. 1993; Natta 2003; Kozlowski 2002; Damasceno-Junior et al. 2004; Maingi et Marsh 2006). The riparian forests are frequently disturbed by floods and debris flows, creating a complex shifting mosaic of landforms over spatial scale. Seasonal variations in discharge and wetted areas create environmental conditions that challenge even the most tolerant species. Nearly every year, most riparian plants are subjected to floods, erosion, abrasion, drought, and occasionally toxic concentrations of ammonia in addition to the normal biotic challenges; the life-history strategies of most riparian plants are such that extreme conditions are either endured, resisted, or avoided (Agee 1993; Naiman and Decamps 1997; Grime 1979; Suzuki et al. 2002). Consequently, plant species diversity varies considerably in space and in time in riparian forests. So, the low number of species along semi-permanent rivers could be explained by the low number of species with large diameters which are adapted to the extreme conditions that species must support; drought in the dry season and flood in the wet season. Indeed, riparian forests of semi-permanent rivers are highly adapted to flood-pulse. Along permanent rivers, despite the high variation, there always have water which provides humidity for trees. Riparian forests of stream are submitted to fewer micro sites conditions variation that can explain the high species richness. However, according to the Shannon Evenness the distribution of species is fairly even along the different types of riparian forests. The even distribution of species along riparian forests is in agreement with authors in West Africa (Natta 2003; Kokou et al. 2008; N'da et al. 2008). This high evenness could be attributed to the ecological succession (Osborne 2000). The similarity in species composition between the different riparian forests was generally low. The similarity between riparian forest of permanent and semi-permanent rivers was higher. The low level of similarity between the different types of riparian forests, and hence the high beta diversity, accentuates the importance of patches in maintaining high species diversity at larger spatial (landscape) scales in ecosystems.

Specie such as *Pterocarpus santalinoides*, *Syzygium guineense*, *Cola laurifolia, Dialium guineense*, *Vitex chrysocarpa* and *Morelia senegalensis* are seen mainly along permanent and semi-

permanent rivers. These species are seen at all latitudes along rivers in Benin (Natta 2003) and at the south-sudanian sector of Burkina Faso. Along streams in the north Benin, species such as *Berlinia grandiflora*, *Khaya senegalensis* are encountered in riparian forest of streams in Burkina Faso too. *Diospyros mespiliformis, Piliostigma reticulatum, Mitragyna inermis, Acacia seyal, Anogeissus leiocarpa* encountered in riparian forest along temporary rivers are encountered in riparian forests at national park of Zakouna in South East of Tchad (Poilecot et al. 2009). Flora of riparian forest of rivers is more dependent of frequent floods than the flora along streams, where the surrounding vegetation greatly influences stream side vegetation (Meave et Kellman 1994; Natta 2003). Natural flows are characterized by temporary and spatial heterogeneity in the magnitude, frequency, duration, timing, rate of change, and predictability of discharge. These characteristics, for a specific river or a collection of rivers within a defined region, shape species life histories over evolutionary (millennial) time scales as well as structure the ecological processes and productivity of aquatic and riparian communities (Naiman 2008).

The higher richness of Rubiaceae in riparian forests along permanent and semi-permanent rivers can be related to flooding (Speed sided and high level of water) and Caesalpiniaceae related to few inundation (temporary rivers and streams). In savannah area of sudano-sahelian zone Combretaceae and Mimosaceae are the most important families in the ligneous strata (Ouédraogo 2006; Poilecot & al. 2009). The importance of these families in the riparian forests of temporary rivers reflects the great presence of savannah species in these riparian forests. Generally, Rubiceae and Caesalpiniaceae increase with humidity (Ouédraogo 2006; Bognounou et al. 2009). For the most richness families, there were Ceasalpiniaceae (16), Rubiaceae (15), Mimosaceae (15) Combretaceae (11) and Moraceae (8). In Benin, Natta (2003) found also Leguminoseae (Ceasalpiniaceae, Mimosaceae and Fabaceae), Euphorbiaceae, Rubiaceae and Annonaceae as the most species-families rich in riparian forests. Symbiotic dinitrogen fixation has been suggested to improve the adaptation of legume trees to waterlogged conditions (Koponen et al. 2004), and partially explain their abundance in forested tropical wetlands.

Complex interactions among hydrology, geomorphology, light, temperature, and fire influence the structure, dynamics and composition of riparian zones (Stolnack and Naiman 2010). Tree density of riparian forests in Burkina Faso (233−727 indvaduals·ha^{-1}) are nearly similar to those in Benin (Natta 2003) and in Côte d'Ivoire (Denguealdhe 1999) with respectively 253−785 indvaduals·ha^{-1} and 376−649 indvaduals·ha^{-1}. But, tree density in our study could be low if we have considered only stems with a dbh ≥ 10 cm like in Benin and Côte d'Ivoire. Values of basal area of riparian forests in Burkina Faso (8.25−31.02 m²·ha^{-1}) are lower than those of some West African riparian forests in Benin with 23−59 m²·ha^{-1} and in Côte d'Ivoire with 25−59 m·ha^{-1}. The high density is found in riparian forests of permanent and semi-permanent rivers and the low density in riparian forest of streams and temporary rivers. This result could be explained by micro-site conditions, water flow effect and species biology. Stem sizes tend to be smaller and stem densities higher in riparian forest of permanent and semi-permanent rivers than riparian forests of streams and temporary rivers. Indeed, channel migration is slow in streams and temporary rivers and fast in semi-permanent and permanent rivers. According to the waterways flow speed, it can transported solid that could provoke abrasion and trees breaking. These disturbances can stimulate vegetative reproduction of riparian species. The small size of stem can be explained by this effect. In addition, the species along permanent and semi-permanent rivers are represented by more multi-stems species. According to authors depending on the type of stream and channel hydraulics, they substantially influence the composition and demography of the vegetative communities (Maingi and Marsh 2002). Many riparian plants possess adaptations allowing them to recover and reproduce by root suckering, adventitious root development on plant fragments, and stem flexibility (Naiman and Décamps 1997). The low density and high average dbh, in riparian forest of stream and temporary rivers can be explained by the large old trees. Thus, the general trend appeared to be that the harsher the environment was (more frequent flooding), less different species were collected, more individual trees census were taken, and generally, the size of trees decreased (Koponen et al. 2004).

For the results in diameter class distribution, similar results were found by other authors (Meave and Kellman 1994; Natta 2003). The decreasing curve has a reverse (J-shaped) distribution typical of natural forest regenerating from seed. It suggests a stable size and age class distribution. Most abundant species among the flood-tolerant species of riparian forest are certainly at a stage of equilibrium with the climatic and soil conditions (Natta 2003).

Conclusion

Species richness, taxonomic diversity, species diversity and the stand structure are influenced by phytogeographical gradient and the both water regime and channel width of watercourse. So the networks of remaining riparian forests could therefore contribute to the maintenance of regional biodiversity. This consideration demands a broader perspective in planning the management of riparian forests. The hydrologic regimes are of primary importance in managing riparian forests. To fulfil ecological functions of riparian systems related to biodiversity, habitat, information flow, biogeochemical cycles, microclimate, and resistance and resilience to disturbances, it is needed to delineate and classify them along watercourses throughout the country.

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Appendix 1. List of all woody species recorded in riparian forests along four watercourses types in the phyto-geographical sectors of Burkina Faso

Species	Families	Watercourse type				Phytogeographical sectors				Species
		PR	SPR	TR	ST	N-sah.	S-sah.	N-sud.	S-sud.	
Abrus precatorius L.	Fabaceae	*			*				*	3
Acacia ataxacantha DC.	Mimosaceae			*			*			2
Acacia dudgeonii Craib	Mimosaceae				+				+	2
Acacia erythrocalyx Brenan	Mimosaceae	+		*	*	*	*	+	*	7
Acacia gourmaensis A. Chev.	Mimosaceae			*				*		2
Acacia macrostachya Rchb. ex G.Don	Mimosaceae			*				*		2
Acacia nilotica Delile	Mimosaceae			+		+	+	*		4
Acacia polyacantha Willd.	Mimosaceae	+			+			+	+	4
Acacia raddiana Savi	Mimosaceae			+		+				2
Acacia seyal Delile	Mimosaceae			+		+	+	+		4
Acacia sieberiana DC.	Mimosaceae	*	+	+	*		+	+	+	7
Adansonia digitata L.	Bombacaceae			*				*		2
Albizia chevalieri Harms	Mimosaceae	+			+			+	+	4
Albizia zygia J.F. Macbr.	Mimosaceae				+				+	2
Alchornea cordifolia Müll. Arg.	Euphorbiaceae				+				+	2
Allophylus africanus P. Beauv.	Sapindaceae	*							+	2
Allophylus spicatus Radlk.	Sapindaceae	*		*	+			*		4
Ancylobotrys amoena Hua	Apocynaceae				*				*	2
Andira inermis (Wright) DC.	Fabaceae				*				*	2
Annona senegalensis Pers.	Annonaceae				*				*	2
Anogeissus leiocarpa Guill. & Perr.	Combretaceae	+		+	+	+	+	+	+	7
Anthocleista procera Lepr. ex Bureau	Loganiaceae				*				*	2
Antiaris africana Engl.	Moraceae				+				+	2
Antidesma rufescens Tul	Euphorbiaceae			*				*		2
Antidesma venosum E.Mey. ex Tul.	Euphorbiaceae	+	+		*			+	+	5
Apodostigma pallens (Planch. ex Oliv.) Wilczek	Celastraceae	*			*				+	3
Asparagus africanus Lam.	Liliaceae			*				*		2
Baissea multiflora A. DC.	Apocynaceae				*				*	2
*Balanites aegyptiaca (*Linn.) Del.	Balanitaceae			+		+	+	+		4
Berlinia grandiflora Hutch. & Dalziel	Caesalpiniaceae	+			+				+	3
Borassus aethiopum Mart.	Arecaceae			*		*				2
Breonadia salicina (Vahl) Hepper & J.R.I.Wood	Rubiaceae				+				+	2
Bridelia ferruginea Benth.	Euphorbiaceae				*				*	2
Bridelia micrantha Baill.	Euphorbiaceae			*	*			*	*	4
Cadaba farinosa Forssk.	Capparaceae		*						*	2
Calamus deerratus Mann & Wendl.	Arecaceae				*				*	2
Calyptrochilum christyanum (Rchb. f.) Summerh.	Orchidaceae				*				*	2
Capparis corymbosa Lam	Capparaceae	*		*				*		3
Capparis tomentosa Lam.	Capparaceae			*	*			*	*	4
Carapa procera DC.	Meliaceae				+				+	2
Cassia sieberiana DC.	Caesalpiniaceae	*	*	+	+			+	+	6
Cassipourea congoensis R. Br.	Rhizophoraceae	+							+	2
Ceiba pentandra (L.) Gaert.	Bombacaceae			*	+			*	+	4
Celtis toka (Forssk.) Hepper & Wood	Ulmaceae				+				+	2
Clerodendrum capitatum Schumach. & Thonn.	Lamiaceae				*				*	2
Coffea ebracteolata (Hiern) Brenan	Rubiaceae	*							*	2
Cola cordifolia R. Br.	Sterculiaceae				+				+	2
Cola laurifolia Mast.	Sterculiaceae	+	+		+			+	+	5
Combretum aculeatum Vent.	Combretaceae			*		*	*	*		4
Combretum adenogonium Steud. ex A. Rich.	Combretaceae	+		+				+		3
Combretum collinum Fresen.	Combretaceae			*				*		2

Continue Appendix 1

Species	Families	Watercourse type				Phytogeographycal sectors				Species
		PR	SPR	TR	ST	N-Sah.	S-sah.	N-sud.	S-sud.	
Combretum glutinosum Guill. & Perr.	Combretaceae			+				+		2
Combretum micranthum G. Don	Combretaceae			+	*	+	+	+	*	6
Combretum molle R. Br. ex G. Don	Combretaceae			+				+		2
Combretum nigricans Leprieur. ex Guill. & Perr.	Combretaceae	*		+				+		3
Combretum paniculatum Vent.	Combretaceae	+		*	*		*	+	*	6
Cordia sinensis Lam.	Boraginaceae				+				+	2
Crateva adansonii DC.	Capparaceae	*		+	*	+	*	*	*	7
Crossopteryx febrifuga Benth.	Rubiaceae			+				+		2
Croton nigritanus Scott-Elliot	Euphorbiaceae	*	*		*				*	4
Croton scarciesii Scott-Elliot	Euphorbiaceae	*							*	2
Dalbergia bignonae Berhaut	Fabaceae				+				+	2
Daniellia oliveri (Rolfe) Hutch. & Dalziel	Caesalpiniaceae			+				+		2
Desmodium gangeticum DC.	Fabaceae			*	*			*	*	4
Desmodium velutinum DC.	Fabaceae		*		*				*	3
Detarium microcarpum Guill. & Perr.	Caesalpiniaceae			+	+			+	+	4
Detarium senegalense J.F. Gmel.	Caesalpiniaceae				+				+	2
Dialium guineense Willd.	Caesalpiniaceae	+			+				+	3
Dichrostachys cinerea (L.) Wight & Arn.	Mimosaceae			+	*			+	*	4
Diospyros mespiliformis Hochst. ex A. DC.	Ebenaceae	+	+	+	+	+	*	+	+	8
Dissomeria crenata Hook. f.	Dioncophyllaceae	+			+				+	3
Elaeis guineensis Jacq.	Arecaceae				+				+	2
Embelia guineensis Baker	Myrsinaceae	*							*	2
Entada abyssinica Steud.	Mimosaceae				*				*	2
Entada africana Guill. & Perr.	Mimosaceae				*				+	2
Entada wahlbergii Harv.	Mimosaceae	+							+	2
Erythrophleum suaveolens (Guill. & Perr.) Brenan	Caesalpiniaceae				+				+	2
Fadogia agrestis Schweinf. ex Hiern	Rubiaceae				*				*	2
Feretia apodanthera Delile	Rubiaceae	*		+	*	+	+	*	*	7
Ficus asperifolia Miq.	Moraceae	*							*	2
Ficus congensis Engl.	Moraceae				+				+	2
Ficus exasperata Vahl.	Moraceae				*				*	2
Ficus glumosa Delile	Moraceae				+				+	2
Ficus natalensis Hochst.	Moraceae				+				+	2
Ficus sur Forssk.	Moraceae				+				+	2
Ficus sycomorus L.	Moraceae				+				+	2
Ficus trichopoda Baker	Moraceae				+				+	2
Ficus umbellata Vahl	Moraceae				*				*	2
Flabellaria paniculata Cav.	Malpighiaceae	*			*				*	3
Flacourtia flavescens Willd.	Flacourtiaceae	*			*				*	3
Flemingia faginea (Guill. & Perr.) Baker	Fabaceae		*	*				*	*	4
Garcinia livingstonei T. Anderson	Clusiaceae	+	+					+	+	4
Garcinia ovalifolia Oliv.	Clusiaceae				+				+	2
Gardenia imperialis Schumach	Rubiaceae				+				+	2
Gardenia ternifolia Schumach	Rubiaceae	*		*	*			*	*	5
Grewia bicolor Juss.	Tiliaceae			+				+		2
Grewia lasiodiscus K. Schum.	Tiliaceae			*	*			*	*	4
Guiera senegalensis J.F. Gmel.	Combretaceae			*		*	*	*		4
Gymnema sylvestre (Retz.) Schult.	Asclepiadaceae	*	*	*				*	*	5
Hannoa undulata Planch.	Simaroubaceae				*				*	2
Holarrhena floribunda T. Durand. & Schinz	Apocynaceae				+				+	2
Hymenocardia acida Tul.	Euphorbiaceae				*				*	2
Hymenocardia heudelotii Müll. Arg.	Euphorbiaceae	+							+	2
Indigofera macrophylla Schumach	Fabaceae	*							*	2

Continue Appendix 1

Species	Families	Watercourse type				Phytogeographical sectors				Species
		PR	SPR	TR	ST	N-sah.	S-sah.	N-sud.	S-sud.	
Ixora brachypoda DC.	Rubiaceae				*				*	2
Keetia cornelia (Cham. & Schlecht.) Bridson	Rubiaceae	+	*	*	*			+	*	6
Keetia mannii (Hiern) Bridson	Rubiaceae				*				*	2
Keetia venosa Oliv. Bridson	Rubiaceae	*			*				*	3
Khaya senegalensis A. Juss.	Meliaceae	+		+	+			+	+	5
Kigelia africana (Lam.) Benth.	Bignoniaceae				+				+	2
Landolphia heudelotii A. DC.	Apocynaceae				*				*	2
Lannea acida A. Rich.	Anacardiaceae			+	+			+	+	4
Lannea barteri (Oliv.) Engl.	Anacardiaceae				+				+	2
Lannea microcarpa Engl. & K. Krause	Anacardiaceae			+				+		2
Lecaniodiscus cupanioides Planch.	Sapindaceae				+				+	2
Leptadenia hastata Decne	Asclepiadaceae			*		*	*	*		4
Loeseneriella africana (Willd.) Wilczeck	Asclepiadaceae	+	*	*	*			+	*	6
Lonchocarpus cyanescens Benth.	Fabaceae				*				*	2
Macrosphyra longistyla Hook.F.	Rubiaceae				*				*	2
Malacantha alnifolia Pierre	Sapotaceae				+				+	2
Mallotus oppositifolius Müll. Arg.	Euphorbiaceae		*		*				*	3
Manilkara multinervis Dubard	Sapotaceae	*			+				+	3
Manilkara obovata (Sabine & G. Don) J.H. Hemsl.	Sapotaceae	+							+	2
Maranthes polyandra (Benth.) Prance	Chrysobalanaceae				*				*	2
Margaritaria discoidea (Baill.) Webster	Euphorbiaceae				+				+	2
Maytenus senegalensis (Lam.) Exell	Celastraceae			*				*		2
Milicia excelsa (Welw.) C.C. Berg	Moraceae				+				+	2
Mimosa pigra L.	Mimosaceae	*	*						*	3
Mimusops kummel Bruce ex A. DC.	Sapotaceae				+				+	2
Mitragyna inermis (Willd.) Kuntze	Rubiaceae	+	+	+	+	+	+	+	+	8
Morelia senegalensis A. Rich.	Rubiaceae	+	+		*			+	+	5
Mucuna poggei Taub.	Fabaceae				*				*	2
Nauclea latifolia Sm.	Rubiaceae	+			+			+	+	4
Nauclea pobeguinii Merr.	Rubiaceae				+				+	2
Ochna rhizomatosa (Tiegh.) Keay	Ochnaceae				*				*	2
Olax subscorpioidea Baill.	Olacaceae				*				*	2
Oncoba spinosa Forssk.	Flacourtiaceae				+				+	2
Opilia celtidifolia Endl. Ex Walp	Opiliaceae				+				+	2
Oxystelma bornouense R. Br.	Asclepiadaceae	*							*	2
Oxytenanthera abyssinica Munro	Poaceae				*				*	2
Pachystela pobeguiniana Pierre & Dubard	Sapotaceae	*							*	2
Pandanus candelabrum P. Beauv.	Pandanaceae				*				*	2
Parinari congensis Didr.	Chrysobalanaceae		+						+	2
Parkia biglobosa (Jacq.) R. Br. ex G. Don	Mimosaceae				+				+	2
Paullinia pinnata L.	Sapindaceae	+	+	*	*			+	+	6
Pavetta corymbosa (DC) F.N. Williams	Rubiaceae				*				*	2
Phoenix reclinata Jacq.	Arecaceae				+				+	2
Phyllanthus muellerianus (Kuntze) Exell	Euphorbiaceae	+	*		*			+	*	5
Phyllanthus reticulatus Poir.	Euphorbiaceae	*	*		*				*	4
Piliostigma reticulatum (DC.) Hochst.	Caesalpiniaceae			+	*	+	+	+	*	6
Piliostigma thonningii (Schumach) Milne-Redh.	Caesalpiniaceae	+		+	+			+	+	5
Psychotria psychotrioides (DC.) Roberty	Rubiaceae				*				*	2
Psychotria vogeliana Benth.	Rubiaceae				*				*	2
Pterocarpus erinaceus Lam.	Fabaceae			+	+			+	+	4
Pterocarpus lucens Lepr. ex Guill. & Perr.	Fabaceae			+		+	+			3
Pterocarpus santalinoides L'Hér. ex DC.	Fabaceae	*		*	+			+	+	5
Raphia sudanica A. Chev.	Arecaceae				*				*	2

Continue Appendix 1

Species	Families	Watercourse type				Phytogeographical sectors				Species
		PR	SPR	TR	ST	N-sah.	S-sah.	N-sud.	S-sud.	
Rauvolfia vomitoria Afzel.	Apocynaceae				+				+	2
Rourea minor (Gaertn.) Alston	Connaraceae				*				*	2
Rytigynia senegalensis Blume	Rubiaceae	*	*	*	*			*	*	6
Saba comorensis (Bojer) Pichon	Apocynaceae				+				+	2
Saba senegalensis (A. DC.) Pichon	Apocynaceae	+		+	*		+	+	*	6
Salacia pyriformis Steud.	Celastraceae	*	+						+	3
Salacia stuhlmanniana Loes	Celastraceae	*							*	2
Sapium grahamii Prain	Euphorbiaceae				*				*	2
Secamone afzelii (Roem. & Schult.) K. Schum.	Asclepiadaceae				*				*	2
Securidaca longepedunculata Fresen	Polygalaceae			*				*		2
Securinega virosa (Roxb. ex Willd.) Baill.	Euphorbiaceae			*	*		*	*	*	5
Sesbania sesban (L.) Merr.	Fabaceae	*						*		2
Smilax anceps Willd.	Smilacaceae				*				*	2
Sterculia tragacantha Lindl.	Sterculiaceae				*				*	2
Stereospermum kunthianum Cham.	Bignoniaceae			*				*		2
Strophanthus sarmentosus DC.	Apocynaceae				*				*	2
Strychnos spinosa Lam.	Loganiaceae			*				*		2
Strychnos usambarensis Gilg ex Engl.	Loganiaceae	*							*	2
Syzygium guineense DC.	Myrtaceae	+	+		+			+	+	5
Tacazzea apiculata Oliv.	Asclepiadaceae	*	*	*	*	*	*	*	*	8
Tamarindus indica L.	Caesalpiniaceae	*		+	*			+	*	5
Tapinanthus globiferus Tiegh.	Loranthaceae			*		*				2
Tarenna pavettoides (Harv.) Sim	Rubiaceae	*	*	*				*	*	5
Tectona grandis L. f.	Lamiaceae				+				+	2
Terminalia avicennioides Guill. & Perr.	Combretaceae			*				*		2
Terminalia laxiflora Engl.	Combretaceae				+				+	2
Tetracera alnifolia Willd.	Dilleniaceae				+				+	2
Tricalysia okelensis Hiern	Rubiaceae				*				+	2
Uapaca heudelotii Baill.	Euphorbiaceae				+				+	2
Uvaria chamae P. Beauv.	Annonaceae	*			+				+	3
Vitellaria paradoxa C.F. Gaertn.	Sapotaceae			+	*		+	+	*	5
Vitex chrysocarpa Planch.	Verbenaceae	*	+					+	+	4
Vitex doniana Sweet	Verbenaceae			+	+			+	+	4
Voacanga africana Stapf ex Scott-Elliot	Apocynaceae				+				+	2
Xylopia parviflora Benth.	Annonaceae	+	+		+				+	4
Zanthoxylum zanthoxyloides (Lam.) B. Zepernick & Timler	Rutaceae				*				*	2
Ziziphus mauritiana Lam.	Rhamnaceae	+		+			+	+		4
Ziziphus mucronata Willd.	Rhamnaceae	*		*	*			*	*	5
Ziziphus spina-christi Willd.	Rhamnaceae		*						*	2
		68	29	71	139	19	23	77	162	

PR: Permanent Rivers; SPS: Semi-permanent Rivers; TR: Temporary Rivers; Streams; N-sah. : North Sahelian; S-sah.: South Sahelian; N-sud.: North Sudanian;

S-sud. South Sudanian, *: DBH <5 cm, +: DBH ≥ 5 cm.